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H. P. HITCHCOCK

DEPARTMENT OF THE ARMY PROJECT No. 5B03-03-001
ORDNANCE RESEARCH AND DEVELOPMENT PROJECT No. TB3-0108

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HPHitchcock/plg
Aberdeen Proving Ground, Md.
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ABSTRACT

Fowler, Gallop, Lock and Richmond found that most of the Magnus moment damping factors deduced from their yaw card firings made in 1919 were negative. Thinking these factors should be essentially positive, they ignored the Magnus moment damping factors completely, considering only the damping in pitch and that due to the crosswind force. Many recent experiments have shown that the Magnus moment coefficient derived from Fowler's* data ar of the same order of magnitude and sign as those derived from later tests.

* In the following, for the sake of brevity, the names of the other authors are frequently omitted.

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Fowler, Gallop, Lock and Richmond[1] deduced the damping of the yaw of 3-inch projectiles from the holes in cardboard screens. Specifically, the damping of the maximum and minimum yaw is related to the stability factor and the combinations $h + \kappa$ and $h - \kappa + 2\gamma$, where

h is the yawing moment damping factor,

κ the cross wind force damping factor,

γ the Magnus moment damping factor.

These values are tabulated in Fowler's Table VII, page 383 (the rolling moment damping factor is negligible).

The cross wind force damping factor was also computed from the cross wind force coefficient, which was determined from the drag coefficient and the normal force coefficient obtained by firing shell with two different positions of the center of gravity. Hence, h and γ could be computed. Most of the resulting values of γ were negative. According to Fowler, "it is natural to expect γ to be small and positive, which does not fit in with the observations. Further experiments would be needed to throw light on all these points" (pp. 355 and 356). Consequently, h was computed on the assumption that $\gamma = 0$, and tabulated in Table VII.

Since 1920, many experiments have been conducted to determine the yawing motion of projectiles. They indicate that both positive and negative values of the Magnus moment occur; in fact, it is usually negative at supersonic velocities, but positive at subsonic velocities. A negative moment simply means that the center of the Magnus force is behind the center of gravity.

In order to compare the results of various tests, the Magnus moment coefficient has been tabulated (see Table I, II and III). The Magnus moment coefficient is computed by the relation

$$K_J = \gamma A/\rho d^4 v,$$

where

K_J is the Magnus moment coefficient (sometimes denoted K_T)

A the axial moment of inertia,

ρ the air density,

d the caliber,

v the velocity,

Table I gives the damping factors and Magnus moment coefficients based on Fowler's data, obtained from firings in January and February 1919. These pertain to a 3-inch shell with a standard blunt fuze or a long ogival plug. The following table gives the length of the fuzed shell and the distance from the center of gravity to the base.

Type	Head	Length	CG to Base
		cal	cal
I	Std fuze	3.84	1.542
II	Std fuze	3.84	1.708
III	Std fuze	3.84	1.401
IV	Long plug	4.38	1.655

Table II gives the Magnus moment coefficients determined from yaw screen firings conducted from 1939 to 1946. The yaw screens consisted of photographic paper for the caliber .30, caliber 50 and 20-mm projectiles; thin cardboards for the 37-mm projectiles. In most cases, the yaw screen technique was unable to detect a minimum yaw different from 0. If the minimum yaw is 0,

$$h - \kappa + 2\gamma = 0.$$

Then, since h is greater than κ, γ is negative.

Table III gives the Magnus moment coefficient determined from firings in the spark ranges. Here, there was no interference with the motion of the projectile and the yaw could be measured more accurately than with yaw screens. At subsonic velocities, the coefficients are positive or 0 (for the 105-mm Shell M1, it is 0 when the maximum yaw is about 6°, but varies from 0.01 to 0.30 when the maximum yaw is less than 5.5°). At supersonic velocities, most of the coefficients are negative, except for the 75-mm Shell M334, which has a hemispherical base

Fowler does not give damping factors for shell fired at 900 feet per second, because the maximum yaw increased at this velocity.* At about 1090 feet per second, three of the four types of shell had positive Magnus moments. At supersonic velocities, all but one shell had negative Magnus moments. In general, the Magnus moment coefficients of the British shell have approximately the same magnitude and sign as the American shell.

I am grateful to Mr. C. L. Poor for suggesting this study.

H P. Hitchcock
H. P. HITCHCOCK

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* Fowler had not apparently realized that, for shell of stability factor slightly greater than 1, the yaw might be negatively damped.

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TABLE I

MAGNUS MOMENT COEFFICIENTS

Based on Data in Fowler, Gallop, Lock and Richmond's

"The Aerodynamics of a Spinning Shell"

Shell forms are shown in figure 6, p. 309.

Shell Types are explained in Table III, p. 316.

Mean velocities are given in Table VI, p. 381.

Air densities are given in Table V, pp. 371 to 380.

The values of h and γ were calculated from the tabulated values of κ, $h + \kappa$, and $h - \kappa + 2\gamma$ in Table VII, p. 383.

Shell		Mean Velocity	Damping Factors (sec^{-1})			Magnus Moment Coefficient
			Cross Wind Force	Yawing Moment	Magnus Moment	
Type	Rounds	fps	κ	h	γ	K_J
I	22-24	1090	0.4	1.5	+0.25	+.09
	25,26	1283	0.3	2.1	-0.3	-.09
	27,28	1515	0.4	2.6	-0.85	-.23
	1-4	2114	0.7	1.5	-0.1	-.02
	19-21	2251	0.8	1.4	-0.4	-.07
II	17-19	1091	0.4	1.8	-0.1	-.04
	24	1259	0.2	0.7	+0.05	+.02
	5-7	1553	0.4	3.0	-1.1	-.31
	22,23	1546	0.4	2.9	-0.95	-.26
	1-4	1984	0.6	2.4	-0.6	-.13
III	17-19	1091	0.4	0.3	+0.1	+.04
	20,21	1262	0.2	2.9	-0.95	-.32
	22,23	1526	0.4	2.6	-0.95	-.26
	1-4	1994	0.6	3.6	-0.65	-.14
IV	13-15	1060	0.5	0.2	+0.85	+.33
	16-18	1502	0.5	2.6	-0.45	-.12
	24-26	2071	0.7	4.3	-1.35	-.27

TABLE II

MAGNUS MOMENT COEFFICIENTS

DETERMINED FROM YAW SCREEN FIRINGS

Projectile	Fuze	Reference	Length cal	Velocity fps	K_J
Cal .30 Bullet, Ball M1		2	4.44	2656	-.15
Cal .30 Bullet, Ball M2		2	3.75	2770	-.09
Cal .30 Bullet, Tracer M1		2	4.75	2734	-.22
Cal .30 Bullet, Frangible M22		3	3.75	1370	-.06
Cal .50 Bullet, Ball M1		2	4.77	2540	-.23
Cal .50 Bullet, AP M2		2	4.58	2655	-.10
Cal .50 Bullet, API M8		4	4.58	2830	-.14
Cal .50 Bullet, Inc M23		5	4.48	3460	-.04
20-mm Proj, Ball T4	None	6	4.12	2483	-.10
20-mm Proj, Ball T4	Tracer	6	4.12	2483	+.02
20-mm Shell, HEI Mk1	Percussion	6	4.09	2830	-.12
20-mm Shell, HE T23	PD M75	6	4.09	2800	-.005
37-mm Shot, APC M59	Tracer	7	3.14	3000	-.12
37-mm Shot, AP M80	Tracer	7	2.89	3100	-.26
37-mm Shell, HE M54	PD M56	2	4.02	2000	-.19

TABLE III

MAGNUS MOMENT COEFFICIENTS

DETERMINED BY SPARK PHOTOGRAPHY

Projectile	Fuze	Reference	Length cal	Mach No.	K_J
20-mm Shell, HEI T282E1	PD M505	8	3.82	0.50	+.10
				0.69	+.35
				1.00	+.10
				1.40	-.04
				2.00	-.05
				3.00	-.06
20-mm Shell, HEI T282E1	Time T 321	8	3.80	0.79	+.43
				1.43	-.005
				1.98	-.05
				3.04	-.06
75-mm Shell, HE M334 (T50E2)	VT T73E7B or T73E12	9 (curve 2)	4.93	0.91	+.30
				1.00	+.61
				1.07	+.62
				1.29	+.20
				1.71	+.10
105-mm Shell, HE M1	PD M51A5 or Dummy M73	10	4.70	0.50	.00
				0.80	.00
				0.95	-.22
				1.20	-.06
90-mm Model of 175-mm Shell, HE T203 (8° Boattail)	PD M51A5	11	5.51	1.0 to 2.6	-.09
T203 (Sq. Base)	PD M51A5	11	5.53	1.0 to 2.6	-.06
105-mm Model Type B		12	4.935	0.73	+.15
				0.93	+.15
				1.05	.00
				1.30	+.02
Cal .60 Cone		13	2.98	1.71	-.05
				2.45	-.03
				3.27	-.01
20-mm Cone-cylinder		13	5.12		
Type 11 CG to Base 2.05 Cal				0.87	+.11
				1.48	-.13
Type 21 CG to Base 1.65 Cal				0.81	+.24
				1.44	-.10
				1.83	-.03
Type 25 CG to Base 1.65 Cal				2.01	-.04
Type 22 CG to Base 1.71 Cal				2.71	+.01
				3.43	-.10
Type 23 CG to Base 1.72 Cal				3.47	-.08
Type 31 CG to Base 1.20 Cal				0.91	+.12
				1.28	-.08

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